

AD-A113 546

WASHINGTON UNIV SEATTLE DEPT OF ELECTRICAL ENGINEERING F/G 20/14  
MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE-ETC(U)  
APR 82 A ISHIMARU N00014-78-C-0723

UNCLASSIFIED

TR-4-ONR

NL

1-1  
AD-A113 546



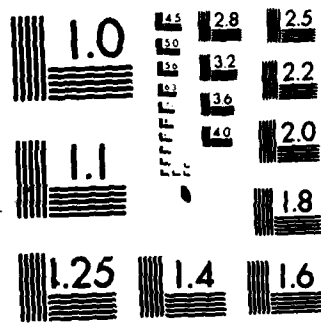
END

DATE

FILED

5-82

DTIC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

12

DEPARTMENT OF ELECTRICAL ENGINEERING  
University of Washington  
Seattle, WA 98195

Annual Summary Report

by

Akira Ishimaru

April 1982

MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE

ONR Contract N00014-78-C-0723

September 1, 1981 to August 31, 1982

Dr. B. R. Junker, Contract Monitor  
Code 421  
Director, Physics Program  
Physical Sciences Division  
Office of Naval Research  
800 North Quincy Street  
Arlington, VA 22217

DTIC  
ELECTE  
APR 16 1982  
H

Reproduction in whole or in part is permitted for any purpose of the  
United States Government.

**DISTRIBUTION STATEMENT A**

Approved for public release;  
Distribution Unlimited

82 04 15 054

AD A113546

DTIC FILE COPY

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ONR-TR-4	2. GOVT ACCESSION NO. AD-4113 548	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE		5. TYPE OF REPORT & PERIOD COVERED Annual Summary Report 9/1/81 to 8/31/82
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Akira Ishimaru		8. CONTRACT OR GRANT NUMBER(s) N00014-78-C-0723
9. PERFORMING ORGANIZATION NAME AND ADDRESS University of Washington Department of Electrical Engineering, FT-10 Seattle, WA 98195		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Office of Naval Research Physics Program Office Arlington, VA 22217		12. REPORT DATE April 1982
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		13. NUMBER OF PAGES
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Transmission of optical waves through atmosphere, multiple scattering effects, fog, clouds, rain, hail, snow, Monte-Carlo solution, turbulence, diffusion of light pulse, radiative transfer theory, forward scatter theory, beam waves, Henyey-Greenstein scattering pattern, angular broadening, pulse broadening, coherence bandwidth, coherence time.		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This annual report gives a summary of the work completed and underway on the contract covering the period from September 1, 1981 to April 15, 1982. The work is directed to the investigation of the transmission characteristics of optical waves with wavelengths in the range of 1-15 $\mu$ m through various atmospheric conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers. Progress was made on the thorough understanding of plane wave transmission characteristics through fog.		

1. Principal Investigator: Akira Ishimaru

2. Contract Description

This contract is directed to the investigation of the transmission characteristics of a wave with the wavelengths in the range of  $1\ \mu\text{m}$  to  $15\ \mu\text{m}$  through various atmospheric conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers.

3. Scientific Problem

The wave transmission characteristics through a dense medium needs further study. The polarization effects due to non-spherical scatterers and the data transmission rate through such media must be clarified. Numerical calculations for various cases should be performed to arrive at useful transmission codes.

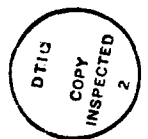
4. Scientific and Technical Approach

We have successfully used the matrix eigenvalue technique and extended it to include the Stokes vectors and polarization effects. We also developed formulations to include the pair-correlation between particles in a dense scattering medium.

5. Progress

For the past year, we have made significant progress in understanding of the transmission characteristics of a wave through the atmosphere. We have completed the calculation of the exact transmission characteristics of plane optical waves through fog in the wavelengths of  $0.5\ \mu\text{m}$  to  $15\ \mu\text{m}$  based on the matrix eigenvalue technique, including polarization effects. We also clarified the characteristics of the coherent field in a dense medium.

Accession For	DTIC GRA&H
DTIC TAB	Unannounced
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or Special
	A



## 6. Publications

### Journal Publications with ONR Sponsorship

1. A. Ishimaru and K. J. Painter, "Backscattered pulse shape due to small-angle multiple scattering in random media," Radio Science, 15, 1, pp. 87-93, January-February 1980.
2. K. Shimizu, A. Ishimaru, L. Reynolds, and A. P. Bruckner, "Back-scattering of a picosecond pulse from densely distributed scatterers," Applied Optics, 18, 20, pp. 3484-3488, October 1979.
3. K. Shimizu and A. Ishimaru, "An experimental test of the reduced effective velocity of light in a diffuse medium," Optics Letters, 5, 5, pp. 205-207, May 1980.
4. A. Ishimaru, "Theory of optical propagation in the atmosphere," Optical Engineering, 20, 1, pp. 63-70, January-February 1981.
5. "Theoretical and experimental study of transient phenomena in random media," Proceedings of the Symposium on Multiple Scattering and Waves in Random Media, ed. by P. L. Chow, W. Kohler, and G. Papanicolaou. North-Holland Publishing Co., Amsterdam, 1981.
6. "Multiple scattering effects on optical propagation in turbulence and particles," NATO-AGARD Conference on "Special Topics on Optical Propagation," pp. 4-1 to 4-12, 1981
7. A. Ishimaru and R. Cheung, "Multiple scattering effects on wave propagation due to rain," Annales des Télécommunications, 35, pp. 373-379, November-December 1980.
8. A. Ishimaru and Y. Kuga, "Attenuation constant of coherent field in a dense distribution of particles," Journal of the Optical Society of America, submitted.
9. A. Ishimaru, "Coherent and incoherent electromagnetic waves in a random distribution of non-spherical particles," in preparation.
10. A. Ishimaru and Y. Kuga, "Diffusion of a beam wave in a scattering medium," in preparation.
11. A. Ishimaru and R. Cheung, "Transmission, backscattering, and depolarization of waves in randomly distributed spherical particles," in preparation.
12. A. Ishimaru, "First-order scattering and depolarization of electromagnetic waves in a random distribution of non-spherical particles," in preparation.

## 6. Publications - continued

### Paper Presentations Related to the Contract Since September 1978

1. A. Ishimaru, "Optical scattering and diffusion in turbulence and scatterers," OSA Meeting, San Francisco, October 1978.
2. K. Shimizu and A. Ishimaru, "Estimation of size distribution of randomly distributed scatterers," OSA Meeting, San Francisco, October 1978.
3. A. Ishimaru, "Forward scatter and diffusion of pulses in a random distribution of scatterers," URSI Meeting, Boulder, November 1978.
4. A. Ishimaru, "Multiple scattering effects on pulse propagation through fog and clouds," Naval Ocean Systems Center Program Review, San Diego, November 1978.
5. A. Ishimaru, "Forward scatter theory and diffusion theory for wave in random media," Bremner Session, National Radio Science Meeting, Seattle, June 1979.
6. A. Ishimaru, "Multiple scattering effects on backscattering of a pulse from terrain," National Radio Science Meeting, Seattle, June 1979.
7. K. J. Painter and A. Ishimaru, "Backscattered pulse shape due to small-angle multiple scattering from a slab of random medium," National Radio Science Meeting, Seattle, June 1979.
8. K. Shimizu, A. Ishimaru, and A. P. Bruckner, "Backscattering of a picosecond pulse from a dense scattering medium," National Radio Science Meeting, Seattle, June 1979.
9. R. L.-T. Cheung and A. Ishimaru, "Multiple scattering of millimeter waves in rain," National Radio Science Meeting, Seattle, June 1979.
10. A. Ishimaru was invited to speak at the Chemical Systems Laboratory Scientific Conference on Obscuration and Aerosol Research, U.S. Army, Aberdeen Proving Ground, Maryland, September 1979.
11. K. Shimizu, A. Ishimaru, and L. Reynolds, "Diffusion and scattering of a picosecond pulse in a dense scattering medium," OSA Meeting, Rochester, October 1979.
12. A. Ishimaru was invited to speak on "Theoretical and experimental study of transient phenomena in random media" at the workshop on "Wave Propagation in Turbulent Media" sponsored by the Mathematics Division, U.S. Army Research Office, at Virginia Polytechnic Institute, Virginia, March 24-27, 1980.

## 6. Publications - continued

### Paper Presentations Related to the Contract Since September 1978

13. A. Ishimaru and R. L.-T. Cheung, "Multiple scattering effects on wave propagation due to rain," URSI Commission F Symposium, Lennoxville, Canada, May 1980.
14. R. Woo, A. Ishimaru and F.-C. Yang, "Radio scintillations during occultations by turbulent planetary atmospheres," North American Radio Science Meeting, Quebec, June 1980.
15. A. Ishimaru, R. L.-T. Cheung, and Y. Kuga, "Diffusion of a beam wave in random discrete scatterers," North American Radio Science Meeting, Quebec, June 1980.
16. A. Ishimaru, "Characterization and remote-sensing of terrain," ICC '80, Seattle, June 1980.
17. A. Ishimaru, "Pulse propagation and diffusion in random media," International URSI Symposium on Electromagnetic Waves, Munich, August 1980.
18. A. Ishimaru, "A statistical model of electromagnetic interference," EMC '80, Baltimore, October 1980.
19. A. Ishimaru and R. L.-T. Cheung, "Incoherent intensities due to rain," National Radio Science Meeting, Boulder, January 1981.
20. A. Ishimaru, "Multiple scattering effects on optical propagation in turbulence and particles," NATO-AGARD Meeting, Monterey, California, April 1981.
21. Y. Kuga and A. Ishimaru, "Attenuation constant of coherent field in dense spherical particles," National Radio Science Meeting, Los Angeles, June 1981.
22. R. L.-T. Cheung and A. Ishimaru, "Transmission and backscattering of optical waves through fog," National Radio Science Meeting, Los Angeles, June 1981.
23. A. Ishimaru, R. A. Sigelmann, K.-L. Peng, and R. Campbell, "A theoretical and experimental study on statistical EMI," IEEE Symposium on Electromagnetic Compatibility, Boulder, August 1981.
24. A. Ishimaru, "Multiple scattering in turbulence, scatterers, and rough surfaces," URSI Symposium on Mathematical Models of Radio Propagation, Washington, DC, August 1981.



## 6. Publications - continued

### Paper Presentations Related to the Contract Since September 1978

25. A. Ishimaru and R. L.-T. Cheung, "Transmission, backscattering, and depolarization of waves in randomly distributed spherical particles," National Radio Science Meeting, Albuquerque, May 1982.
26. R. L.-T. Cheung, "Millimeter and optical waves in rain and fog," Ph.D. Dissertation, Electrical Engineering Department, University of Washington, December 1981.

## 7. Remaining Funds

No unspent funds remaining at the end of the current contract period.

## 8. Personnel

### Graduate Students:

- (a) Koichi Shimizu
- (b) Raymond Chan
- (c) João Machado
- (d) Kirk Painter
- (e) Rudolf Cheung
- (f) Yasuo Kuga

## 9. Graduate Students Who Have Earned Advanced Degrees

- (a) Kirk Painter, M.S. in E.E., Fall 1978
- (b) Koichi Shimizu, Ph.D. in E.E., Summer 1979
- (c) Raymond Chan, M.S. in E.E., Fall 1980
- (d) Rudolf Cheung, Ph.D. in E.E., Fall 1981

**10. Other Government-Sponsored Research****(a) Title: Statistical Study of Electromagnetic Interference**

**Grant No.:** NB82RAC20005  
**Agency:** National Bureau of Standards  
**Term:** December 16, 1981 to December 15, 1982  
**Funding:** \$44,998  
**Principal Investigator:** Akira Ishimaru

**(b) Title: Wave Propagation in Dense Geophysical Media**

**Grant No.:** DAA G29-81-K-0065  
**Agency:** ARO  
**Term:** April 1, 1982 to March 31, 1983  
**Funding:** \$54,142  
**Principal Investigator:** Akira Ishimaru

